TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 16148

March 2011

ICS 13.340.20

English Version

Head and neck impact, burn and noise injury criteria - A Guide for CEN helmet standards committees

Critères relatifs au traumatisme cervico-facial et aux lésions dues aux brûlures et au bruit - Guide destiné aux comités des normes sur les casques de protection du CEN

Kriterien für Verletzungen durch Einwirkung auf Kopf und Hals, Verbrennungen und Lärmverletzungen - Leitfaden für Arbeitsgruppen, die europäische Helmnormen erarbeiten

This Technical Report was approved by CEN on 27 December 2010. It has been drawn up by the Technical Committee CEN/TC 158.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. CEN/TR 16148:2011: E

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Foreword

This document (CEN/TR 16148:2011) has been prepared by Technical Committee CEN/TC 158 “Head protection”, the secretariat of which is held by BSI.

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Introduction

Members of helmet Standards committees frequently need to define limits for test procedures. Such limits relate to test values that indicate the potential for injury and yet it is often difficult for members to know the type and severity of injury that is represented by a given test value. Over the years, criteria have been developed for different body regions and usually these have been derived from a combination of accident and casualty data, and tests on cadavers, cadaver body parts, animals and human volunteers. However, such criteria are often used by the automotive industry as pass/fail values without a clear understanding of human tolerance to injurious forces. This sometimes leads to the mistaken belief that any value below the stated limit implies uninjured and all values above imply a serious or fatal injury.

This misconception gives very little freedom to choose values that are different from the often inappropriate automotive value. This is particularly true for head injury criteria for which values for a helmeted head may be different to those for the unhelmeted head. Many accidents to wearers of helmets, which cover a wide range of activities from horse riding to downhill skiing, result in a closed head injury. This is when the brain is damaged without any skull or external tissue damage. Conversely, head injuries in automotive accidents are much more frequently open head injuries with skull fracture and soft tissue lesions.

Other misconceptions arise because of the failure to understand that human response to a given dose or injurious parameter varies across a range of the population. The dose response curve tends to be "S" (sigmoid) shaped such that as the magnitude of the injurious parameter increases so does the percent of the population that sustains an injury of a given severity. Thus, a family of "S" curves can be generated for a range of injury severity such as AIS and a measurement or criterion such as HIC, the Head Injury Criterion. Unfortunately, the data for such an analysis is generally difficult to obtain because measurements generated by test apparatus do not relate directly to injury severity because a headform for example does not respond in an impact like a human head. Hence, it is necessary to find a relationship between these test measurements and injury severity.

This paper is designed to provide information to convenors that will help in choosing test limits in relation to a particular injury type and severity. It is worth noting that accident investigators use a scale known as the Abbreviated Injury Scale, AIS (AAAM). This was developed (in the USA) so that injury severity could be recorded in databases regardless of the body region and type of injury thus avoiding lengthy medical terms that were unfamiliar and difficult to interpret. This paper begins by reviewing the AIS scale and its application to head and neck injuries and burn injuries. Thereafter, each measurement type is reviewed and the severity of injury for given values is identified where possible. A section on burn injuries and fatigue related to heat exposure has been included to assist with Standards for equipment to protect firefighters. The Appendix describes the skin structure and the category and consequence of burn injuries.

Premature deafness because of high noise levels and the converse problem of over attenuation of auditory warnings was also considered. Suggested levels have been included with details of test methods in Annex A.

1 Abbreviated injury scale, AIS

This is a scale that extends from 0 to 6 where 0 is uninjured and 6 is unsurviveable. Each level can be applied to any body region according to a coding manual developed by the Association for the Advancement of Automotive Medicine (AAAM). Tables 1 and 2 give the scale and injury severity and an indication of the head and neck injuries that would be classified at each level. Table 3 gives similar information for burn injuries by degree, surface area and region of the body.

Table 1 — AIS scale with head injury severity

	AIS 0 uninjured	AIS 1 minor	AIS 2 slight	AIS 3 moderate	AIS 4 serious	AIS 5 severe	AIS 6 unsurviveable
Scalp							
superficial abrasions, contusions, lacerations		X					
major laceration or minor blood loss			X				
blood loss >20% or total scalp loss				X			
Intracranial vessels (arteries)							
laceration					X	X	
Cranial nerves							
contusion, laceration, loss of function			X				
Brain							
swelling, contusions, haemorrhage				X			
haematoma, large >15cc contusion					X		
massive >30cc contusions, diffuse axonal injury, large haematoma						X	
crush, penetrating injury							X
Loss of consciousness							
< 1 hour			X				
1 - 6 hours or < 1 hour with neurological deficit				X			
6 – 24 hours, or 1-6 hours with neurological deficit					X		
> 24 hours, or 6-24 hours with neurological deficit						X	
Skull Fracture							
simple			X				
compound				X			
complex, open, loss of brain tissue					X		

Table 2 — AIS scale with neck injury severity

	AIS 0 uninjured	AIS 1 minor	AIS 2 slight	AIS 3 moderate	AIS 4 serious	AIS 5 severe	AIS 6 unsurviveable
Whole area							
Skin							
superficial abrasions, contusions, lacerations		X					
major laceration or minor blood loss			X				
blood loss >20%				X			
Decapitation							X
Vessels (arteries)							
carotid, jugular and vertebral laceration minor			X				
carotid jugular and vertebral laceration major				X			
Nerves							
vagus injury		X					
phrenic injury			X				
Spine							
hyoid fracture			X				
cord contusion				X			
incomplete cord syndrome					X		
complete cord syndrome or laceration C-4 or below						X	
complete cord syndrome or laceration C-3 or above							X
disc injury without nerve root damage			X				
disc injury with nerve root damage				X			

Table 3 — AIS scale with burn injury severity

	AIS 0 uninjured	AIS 1 minor	AIS2 slight	AIS 3 moderate	AIS 4 serious	AIS 5 severe	AIS 6 unsurviveable
1st degree							
unspecified		X					
2nd degree							
< 10% TBS (Total Body Surface)		X					
3rd degree							
< 10% TBS			X				
< 10% TBS with face, hand or genitalia involvement				X			
2nd or 3rd degree							
10% to 19% TBS			X				
10% to 19% TBS with face, hand or genitalia involvement				X			
20% to 29% TBS				X			
20% to 29% TBS with face, hand or genitalia involvement					X		
30% to 39% TBS					X		
30% to 39% TBS with face, hand or genitalia involvement						X	
40% to 89% TBS						X	
≥ 90%							X
TBS = Total Body Surface							

2 Peak linear acceleration (A.3.1 & A.4)

This is the most frequently used parameter in helmet testing and is derived usually from a tri-axial accelerometer mounted in the headform unless the headform is rigidly supported and then the source is a single axis accelerometer. In both types, the helmet is mounted onto the headform and then the apparatus allowed to fall unimpeded onto a rigid anvil.

Table 4 is a scale published by Newman (1980) and is supported by research that is more recent.

Table 4 — Peak acceleration and typical AIS Equivalent

Peak Acceleration	AIS
< 50 g	AIS 0
50 g – 100 g	AIS 1
100 g – 150 g	AIS 2
150 g – 200 g	AIS 3
200 g – 250 g	AIS 4
250 g – 300 g	AIS 5
> 300 g	AIS 6

Although not specifically stated in the original research paper it should be considered that the above values represent 50th percentile, which means that 50 percent of the population would sustain an injury of a given AIS severity for the corresponding range of acceleration. It is interesting to note that historically, values have been set which correspond to AIS 5 and that this has resulted in helmets that have given reasonable protection.

In some standards, the helmet is mounted onto a fixed headform and then a mass is dropped onto the helmet. Values given in Table 4 may be used with caution provided the falling mass is approximately 5 kg and the headform is attached to an appropriate neck. Replacing the fixed headform test by a falling headform, guided or free-fall, should be considered.

3 Head injury criterion HIC (A.4)

Annex A gives details of the derivation of HIC and the formula is given below.

$$HIC = \left[\left(\frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} a_{res} dt \right)^{2,5} \cdot (t_2 - t_1) \right]_{\max}$$

The benefit of HIC over peak linear acceleration is that HIC is related to time and it is known that pulses with the same peak value but different duration can give a different injury outcome. Unfortunately, HIC and AIS values have never been satisfactorily correlated. Although, recent research (COST 327) has provided tentative values for AIS 2 and AIS 3, see below. Nevertheless, researchers have provided an assessment of the probability of death for HIC ranges. A summary of the various findings is given in Table 5.